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COAST AND GEODETIC SURVEY
H. Arnold Karo, Director

Tellurometer Traverse Surveys

LIEUTENANT HAL P. DEMUTH

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Technical Bulletin Series

This series of Technical Bulletins is inaugurated to present to the personnel of the Coast and Geodetic Survey and to others the results of research and development in the various fields of the Bureau's activities. It is designed for quick publication and dissemination and supersedes The Journal of the Coast and Geodetic Survey, the last issue of which was published in October 1957. Since many of the bulletins will deal with new practices and new techniques, the views expressed will be those of the author and will not necessarily represent final Bureau policy.

Technical Bulletin No. 2 contains a brief description of the Tellurometer, preliminary procedures for its use on geodetic surveys, and the results of field surveys along the Alaska coast and along a highway route in Virginia.

COAST AND GEODETIC SURVEY TECHNICAL BULLETINS

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Tellurometer Traverse Surveys

LIEUTENANT HAL P. DEMUTH

U. S. Coast and Geodetic Survey

DURING the past few months, a new instrument has enabled surveyors to adapt an old method of surveying to a modern need. This equipment has answered a longstanding demand for an accurate, economical, and rapid method of measuring distances. If the surveyor could measure the distance between two intervisible points regardless of the intervening terrain, the most difficult problem presented by the traverse method would be solved. The traverse solution of the location of geodetic points has long been with us, and has been used to great advantage in many types of surveys, from those of ancient Egypt to the present. The limitations imposed by the traverse method have been largely confined to the measurement of the necessary distance between two points. Once that distance is available, the necessary angles can be obtained with methods and instruments that have been proven by time and trial. Distances have had to be measured with a tape, a subtense bar, or by stadia. The latter two methods have rigid limitations on their accuracy; the former is expensive, slow, and in cases of adverse terrain, almost impossible.

In June of 1957, the Coast and Geodetic Survey received its first model of the latest geodetic surveying instrument available--the Tellurometer, a device for measuring the distance between two points by electronic methods. The name is indicative of the function of the instrument, taken from the Latin *tellus* meaning "earth." It is manufactured by Tellurometer (PTY.) Ltd., of Capetown, Union of South Africa.

DESCRIPTION OF INSTRUMENT

The Tellurometer was designed with two basic concepts, in mind--accuracy and portability. Scientists and engineers have long sought a tool to aid in distance measurements that would satisfy high-order accuracy requirements and still be portable enough for field work under adverse terrain conditions. The Tellurometer equipment fulfills these two requirements, having first-order distance measuring capabilities and weighing less than 50 pounds.

Briefly, the instrument consists of two main units, the master and the remote. Each primary unit weighs 38 pounds including its carrying case. In addition, each unit has the following auxiliary equipment: a tripod weighing 8 pounds, a power supply (vibrapack) weighing 10 pounds, and a 6-volt storage battery weighing approximately 15 pounds. The master and remote units are nearly identical in appearance, each resembling a portable television receiver. The cathode-ray tube, several meters, and switches are on the front of the instrument, and a small parabolic reflector is mounted on the back, which is used to beam the electromagnetic energy.

A two-way, duplex radiotelephone system is built into the Tellurometer equipment to allow the two operators to communicate with one another. This feature provides a clear, interference-free, voice radio circuit that expedites the measuring operation.

To measure a distance, one unit is placed at each end of the line. The choice as to which end to place the master unit is not important; either master or remote unit will operate at either end. The manufacturer has stated that the range of the equipment is approximately 40 miles; however, this range will vary with weather conditions. One important criterion that must be met is the intervisibility of the line, which includes the clearance above the terrain and projecting objects. This is most critical, as a line which has sufficient intervisibility for a survey using theodolites would not necessarily be adequate for the Tellurometer, because of the use of ultra-high frequencies.

The System

The Tellurometer system can best be described as a phase and pulse measuring device that operates in much the same manner as other phase comparison and phase measuring navigation systems in use by the Bureau. Pulses are initiated at the master unit, received at the remote unit, analyzed, and retransmitted to the master unit. At the master unit the pulses are presented on a small cathode-ray tube for reading and recording. The indication on the master unit requires no manual operation such as matching pulses, as is done with the shoran or EPI equipment, rather a trace is read directly on a calibrated graticule fastened to the face of the cathode-ray tube.

The instrument measures the time required for an energy pulse to travel from the master to the remote unit and return. The time is measured in terms of a phase-shift of the modulated wave; the unit of measurement is the millimicrosecond, or billionth of a second. Once this value is determined, it is multiplied by a constant factor--

the velocity of propagation—to obtain the distance. Since this constant factor can convert time into any linear units, the resultant distance may be obtained in any desirable unit—meters, feet, statute miles, etc. The final value is divided by two to obtain the length of the line.

Since the Tellurometer system operates on high frequencies, in the range of 3000 megacycles per second, the possibility of energy being reflected from the surrounding terrain cannot be overlooked. By obtaining distance readings (in terms of millimicroseconds of time) at several different frequencies near 3000 megacycles per second, the wave lengths of the energy—hence, the reflective properties of the wave—are varied, giving a random distribution of the observed distances about a mean value. This is comparable to taking several positions with a direction theodolite to eliminate periodic errors in the circle of the instrument.

All recording is done at the master unit, the remote unit requires one operator only. For rapid operation at the master unit, two men are required—an operator and a recorder. If speed is not important, one man can easily read and record all data. About the same amount of time is required to measure a distance as would be required by a skilled observer to occupy a triangulation station having two or three lines. A few simple steps are all that are required for operation of either the master or remote unit.

Master Tellurometer unit. In order to obtain the photograph, the cathode-ray tube light shield was removed and the telephone handset placed on top of the instrument; neither should be done during operations.

Remote Tellurometer unit.

In addition to making the distance measurements, certain weather observations are required for an accurate determination of the length of the line. The master and remote operators are each provided with a psychrometer and a barometer, in order to obtain the observations necessary to compute the index of atmospheric refraction, which is applied to the observed Tellurometer data.

Training Personnel

A Tellurometer distance measurement can be made in about 30 minutes under normal weather conditions with trained operators. This includes setting up the equipment, warming up the instrument, making the observations, and repacking the gear. The term "trained operator" can be misleading. To operate the remote unit the Bureau has trained regular survey field crew personnel. These men are taken from available field parties.

No formal background is necessary; and in 2 hours the new operator can operate the equipment and provide the master unit crew with very satisfactory results. Since the instrument is subject to damage by excessively rough handling, the man selected for this assignment must be of a responsible nature and must be aware of the need for correct procedure and safety of the equipment.

The operator of the master unit is normally the chief of the survey crew. He should be thoroughly familiar with all the necessary features of geodetic surveying, but not necessarily with a background in electronics. He is required to insure that all necessary precautions are taken to obtain an accurate measurement, make all of the observations and be able to compute the final distance. The training period for this assignment is usually about a month.

Since the instrument is fully electronic, it was first thought that a trained electronic technician would be useful as a master unit operator. This would facilitate any repair, maintenance, or overhaul that might be necessary during a project. The first field crew chief assigned to use the instrument was an electrical engineer and could make certain repairs on the equipment. This, however, required several pieces of electronic testing equipment. Without these only minor repairs could be accomplished. The decision therefore was that in the future no electrical engineer will be provided. The master unit operator must be familiar with all of the necessary checks to insure that the instrument is operating properly. If a malfunction is discovered, the instrument will be returned to either the Bureau's electronic laboratory for repair or to the branch office of the manufacturer. When working from or in the vicinity of a major survey ship, several trained technicians are usually available to aid the Tellurometer crew in making repairs. This plan has proved practical.

Accuracy

The accuracy of the equipment has not been precisely determined as yet. The manufacturer has estimated the accuracy to be 3 parts per million of the distance measured plus or minus 2 inches. In other words with lines less than 10 miles in length the 2 inches would be the limiting accuracy, while on lines over 10 miles the 3 parts per million would provide the limiting accuracy. At present, the Bureau has had only a few tests of this single-line accuracy. One measurement was made over a line of 12,800 meters with a difference between the established length and the Tellurometer length of 6 centimeters, providing an accuracy of 1 in 200,000. A second comparison was made over a line 2,600 meters long and provided an accuracy check of 1 in 100,000. These tests were made under average field and weather conditions in the Washington, D. C., area and it can be reasonably assumed that this type of accuracy for single lines could be expected when the instrument is used in normal field operation.

FIELD PROCEDURE

The field procedure for a complete distance measurement is a simple one. The master and remote units and their supporting equipment are taken to the two ends of the line, and each unit mounted on its tripod. The power supply and battery are connected, and the equipment is turned on and allowed to warmup for a period of 10 minutes. Radio communication is then established between the two units and arrangements are made by the operators for final adjustments. The initial weather observations, which are made at both units, are all recorded at the master station. A series of 12 distance readings are taken at specified frequencies. At the conclusion of these measurements, the final weather observations are made and recorded. This completes the necessary field observations.

The Tellurometer system is designed so that one master unit is used with two or more remote

Tellurometer unit setup under a hydrographic signal. Note the dipoles at the focus of the parabolic mirror.

units. At the beginning of a day's work the one master crew and the two remote crews go to their respective stations. The master crew must be located between the two remote stations. The master unit works with the first remote, measures that distance, and informs the operator to move to the next predetermined site. The master unit then uses the second remote unit to obtain that distance, and the master unit is then ready to be moved to a new station site, again arranging the units so that it is between the two remote units. This method can be used to good advantage in almost every type of terrain thus far encountered. By using this skip-over system, the three units can obtain four or five distances in a day.

Preliminary Instructions

Since the Tellurometer traverse method was a new and untried field procedure with the Bureau, the following preliminary instructions were drawn up as a guide for the field party.

1. *Connections to triangulation.*—The Tellurometer traverse is to be connected to triangulation stations, both in position and in azimuth, where these stations are nearby and in every case where it is practicable. Where possible, a triangulation station should be incorporated into the traverse, otherwise the optimum method is to close, with a theodolite, a single triangle in which one corner is a triangulation station and one line is measured by the Tellurometer. Azimuth shall be transferred at the triangulation station. If, for some reason, it is impracticable to occupy the triangulation station, a position connection may be obtained by intersecting that station from three consecutive Tellurometer stations. This method should be avoided where possible.

A position and azimuth tie may be made by observing with the Tellurometer the distance between the triangulation and traverse stations, and swinging azimuths at both ends of the line.

As a last resort, a position connection may be made by measuring the distance between the triangulation and traverse stations with the Tellurometer, and swinging an azimuth onto this line from the traverse station.

2. *Vertical angles.*—Since the slope measurements by the Tellurometer must be reduced to geodetic distances, it is necessary to determine slope as well as elevation.

The vertical angles shall be taken with a theodolite over each measured line in both directions except when one end of the line is not to be occupied for horizontal angles. In this case, vertical angles in one direction will suffice. The height of the instrument and of the target above the station mark shall be carefully measured and recorded in all cases. Similar measurements shall be made for the Tellurometer master and remote stations.

Accurate elevations, as such, are not required for sea-level reduction. These may be taken from a topographic map or determined by an altimeter. However, since slopes must be determined by vertical angles, elevation connections should be made to benchmarks every few miles where these are available. This permits a check on the vertical angle work.

For a theodolite of the Wild T-3 or T-2 type, two observations, direct and reverse, for zenith distances shall suffice, provided these check within 10 seconds. Vertical angles shall, of course, be measured over all Tellurometer lines including those used in connecting triangulation.

Tellurometer unit setup in Alaska protected by a ground observing tent.

3. *Station marks.*—The standard traverse station mark shall be used in Tellurometer traverse work. There shall be one underground and one surface mark, two reference marks but no azimuth mark. Each Tellurometer station at which an angle is to be measured shall be marked, provided the lengths of the Tellurometer distances are at least 1 mile in length. Extra points needed to carry lengths along this scheme, which are spaced closer than 1 mile, shall be marked only temporarily by a small length of pipe or something similar.

4. *General considerations.*—The general plan of reconnaissance, loops, offsets, azimuth lines, and the rest, outlined in Special Publication 137, *Manual of First-Order Traverse*, shall apply to Tellurometer traverse. Because of the ease of measuring distances over rough terrain by Tellurometer, traverse loops with intermediate stations to aid in length measuring should seldom be necessary. Main azimuth lines should seldom be less than 1/4-mile in length.

5. *Horizontal angles.*—Horizontal angle measurements shall conform to the Specifications for First-Order Traverse as outlined in Special Publication 137. Daytime observations are permitted under good conditions. Eight positions of the circle will suffice with the Wild T-3 and twelve positions with the Wild T-2.

6. *Special considerations.*—Since the difficulty of measuring distances with the Tellurometer does not increase with the difficulty of the terrain, the reconnaissance engineer should take full advantage of this to avoid high signals. *It is more economical to carry the traverse over shorter lines which may carry the work off the direct route and back onto it than to build high signals just to keep the work entirely on the direct route at the desired spacing.*

A word of caution is necessary. Reflecting surfaces such as paved highways and water should be avoided as much as possible in planning the Tellurometer lines, since such surfaces could possibly cause adverse reflections in the observations.

The foregoing outline of preliminary instructions were general enough to allow the various field parties several choices under varying conditions. Two specific surveys are presented in this paper. The first traverse was measured on Atka Island in Alaska and the second in the state of Virginia in connection with the Federal Highway Program. Both types of surveys are discussed in order to indicate the different problems encountered and the procedures followed under differing field conditions.

SURVEY IN ALASKA

In order to establish geodetic control along the rugged south coast of Atka Island in the central Aleutians, the writer was assigned to the Ship *Explorer* in June 1957 to make a Tellurometer traverse. Prior surveys had established third-order triangulation across the northern coast of the island; the traverse survey was to originate and terminate along this triangulation scheme. The traverse was in itself to be of second-order accuracy, using the Tellurometer for distance measurements and standard second-order direction theodolites for angular measurements. No particular savings would have resulted in lowering the accuracy to third order.

In the Bechevin Bay area on the north coast of Atka Island (fig. 1), triangulation stations *Sade* 1943, *Head* 1943, and *Oil* 1943 were recovered and station *Baldy* 1957 was established by triangulation. The Tellurometer was checked by measuring the lines *Sade-Baldy* and *Sade-Head*. Traverse stations were established in a southerly direction at about 2-mile intervals, bringing

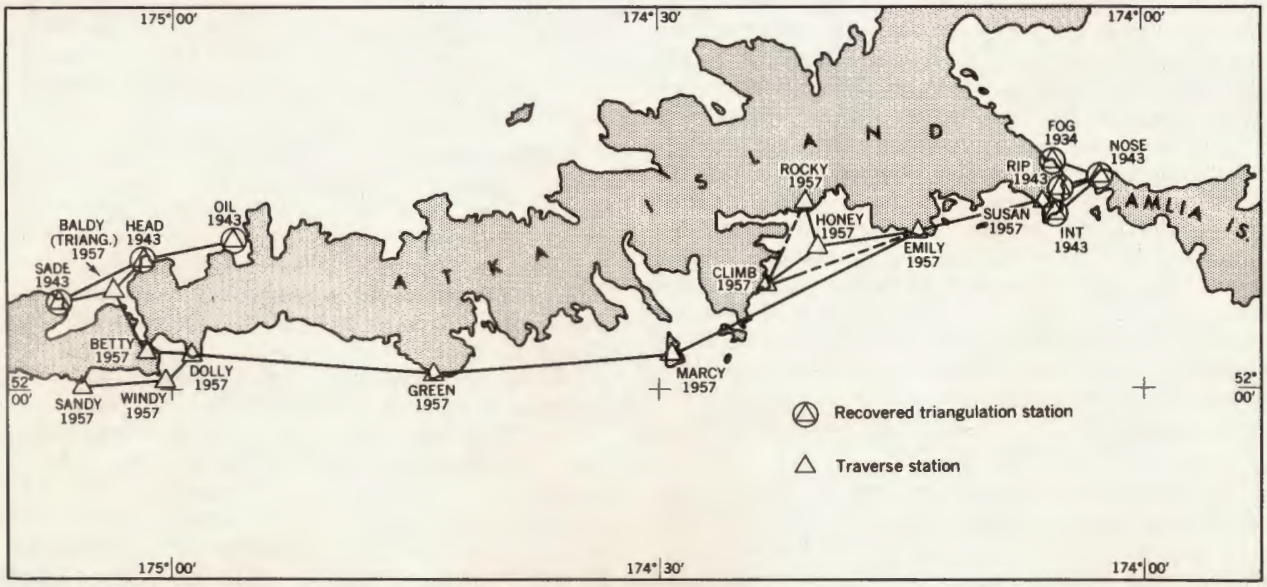

FIG. 1.—Tellurometer traverse, Atka Island, Alaska.

this control to the south side of the island. The general plan then followed was to establish stations in an easterly direction along the south side of the island, finally tying in the survey on triangulation stations *Fog* 1934, *Rip* 1943, and *Int* 1943 on the eastern tip of Atka Island and *Nose* 1943 on the western tip of Amlia Island. Along the south side the distances between stations were increased by taking advantage of various headlands and offshore islands, several distance measurements being about 10 miles. A theodolite was used at each traverse station to obtain the foreward azimuth to the next station. In order to reduce the Tellurometer distances to horizontal measurements, zenith distances were observed, at each station and the elevations computed.

After the field data were determined, they were converted into a final distance measurement. As the computations are not complicated, a trained operator can obtain the final result in approximately 10 minutes.

At the conclusion of the traverse measurements, the field computations showed that an accuracy of 1 in 18,830 was obtained over the total closed portion of the traverse of 77,226 meters.

Weather conditions found during this survey did not affect the operation of the Tellurometer; heavy fogs, rain, and fairly high winds were common, but did not hamper the distance measurements. The time taken, however, for the angular measurements at each station was governed primarily by visibility. Since good visibility does not occur too frequently in the Aleutian area, the angular measurements usually required more time than the Tellurometer observations. The portability of the Tellurometer proved to be excellent. Two men per unit were required for transporting the necessary equipment by backpacking it to the station after being put ashore. Each component of the gear was arranged for backpacking so that no load exceeded 40 pounds per man. The transportation of the men and equipment by launch, skiff, and foot to the station sites was another time-consuming factor. During this survey, as many as 3 distances and the necessary angles were observed in 1 day, when the stations were within 2 miles of each other and landing conditions were favorable. On the longer lines of 10 miles or more, only 1 distance and the necessary angles could be measured per day as most of the day was spent in transporting men and instruments to and from the stations.

In addition to observing the 48-mile basic traverse, several supplemental traverse stations were established on the south side of Atka Island. *Windy* and *Sandy* were added to determine the proposed shoran site at *Sandy*. *Climb*, *Honey*, and *Rocky* were added for future hydrographic use.

The entire project including the establishment of 12 stations and closing the traverse took a total of 14 working days.

SURVEY IN VIRGINIA

At the conclusion of the Alaskan traverse survey, the Tellurometer was transferred to a project in the State of Virginia to assist in establishing the basic control needed in connection with the Federal Highway Program. This project presented several interesting problems. The State required recoverable points, along the proposed route of the new highways, with second-order accuracy. This requires an azimuth error not in excess of 2.0 seconds of arc per main scheme station and a closing error in position not in excess of 1 part in 10,000. These standards could be met in only one way prior to the acquisition of the Tellurometer—by triangulation. To establish a scheme of triangulation along highway routes, many extra points have to be located to provide the necessary width of the scheme to meet the accuracy provisions. The most economical method of providing these geodetic points along the highway would be to traverse along the proposed route, locating points wherever required. The timely advent of the Tellurometer made it possible to provide Virginia with the data required.

The project in Virginia called for liaison between the Coast and Geodetic Survey and the Virginia State Highway Department. The Virginia representative kept in contact with the 2-man reconnaissance party and indicated how much control the State required. The reconnaissance party provided the Tellurometer party with the proposed locations for the stations along the general route of the new highways. The Tellurometer party worked in close cooperation with one of the Bureau's triangulation parties that had been establishing highway control using conventional triangulation methods.

The general plan was simple. The triangulation party, composed of 12 men, was responsible for placing the standard traverse disks in various points outlined on the reconnaissance sketch, building any steel or wooden towers that were considered necessary, and observing all horizontal and vertical angles for this survey. The 4-man Tellurometer party was responsible for obtaining the distance measurements with this instrument and the computations concerned.

The Virginia plan called for geodetic points along the proposed route of the highway with a spacing of about 3 miles between points. The stations could not be directly on the right-of-way, as they would be destroyed during construction. Those selected were mostly on hills, small knolls, or rises near the route. In general, their elevation provided the necessary line-of-sight

between stations and allowed the instrument to be used above the surrounding trees. At many station sites some clearing of surrounding brush or trees was necessary to allow a theodolite to be used. In several cases, steel towers ranging in height from 37 to 77 feet were built to elevate the instruments above either trees or surrounding buildings.

Many different types of work were accomplished during a typical day's schedule: One or two small building crews (consisting of 2 or 3 men each) engaged in setting marks and clearing brush and trees for lines-of-sight; one or two observing teams (from 3 to 5 men each) measuring angles at various stations; and the Tellurometer crew measuring distances between these stations, the number of distances varying from two (on rugged backpack trips) to four or five where accessible by truck. By setting the Tellurometer with a small eccentricity, the angle and distance measurements could be conducted by these crews at the same site at the same time without interferring with each other. The sequence of measurements, angles or distances, was found to be unimportant.

The terrain between Lexington, Va., and the West Virginia border along U. S. Route 60 provided an excellent challenge for the Tellurometer. The land is mountainous and the route of the present highway is tortuous. Locating stations every 3 miles as outlined by the Virginia representative would have been a difficult project had triangulation alone been the only method available. As the mountains are heavily timbered, a large amount of clearing would have been necessary to provide a line-of-sight between the various stations. Several mountaintops would have had to be used in order to provide the scheme with adequate width and strength. Access to these mountains is difficult at best in good weather, but with adverse weather the roads are impassable. Several steel towers would have been necessary to see above existing trees that could not be cut, and the transportation of these towers to the peaks would have been very difficult. By using the Tellurometer and the traverse method, the line was carried along lower elevations, and where any particular site offered difficulties from an access standpoint it was changed without weakening the accuracy of the system.

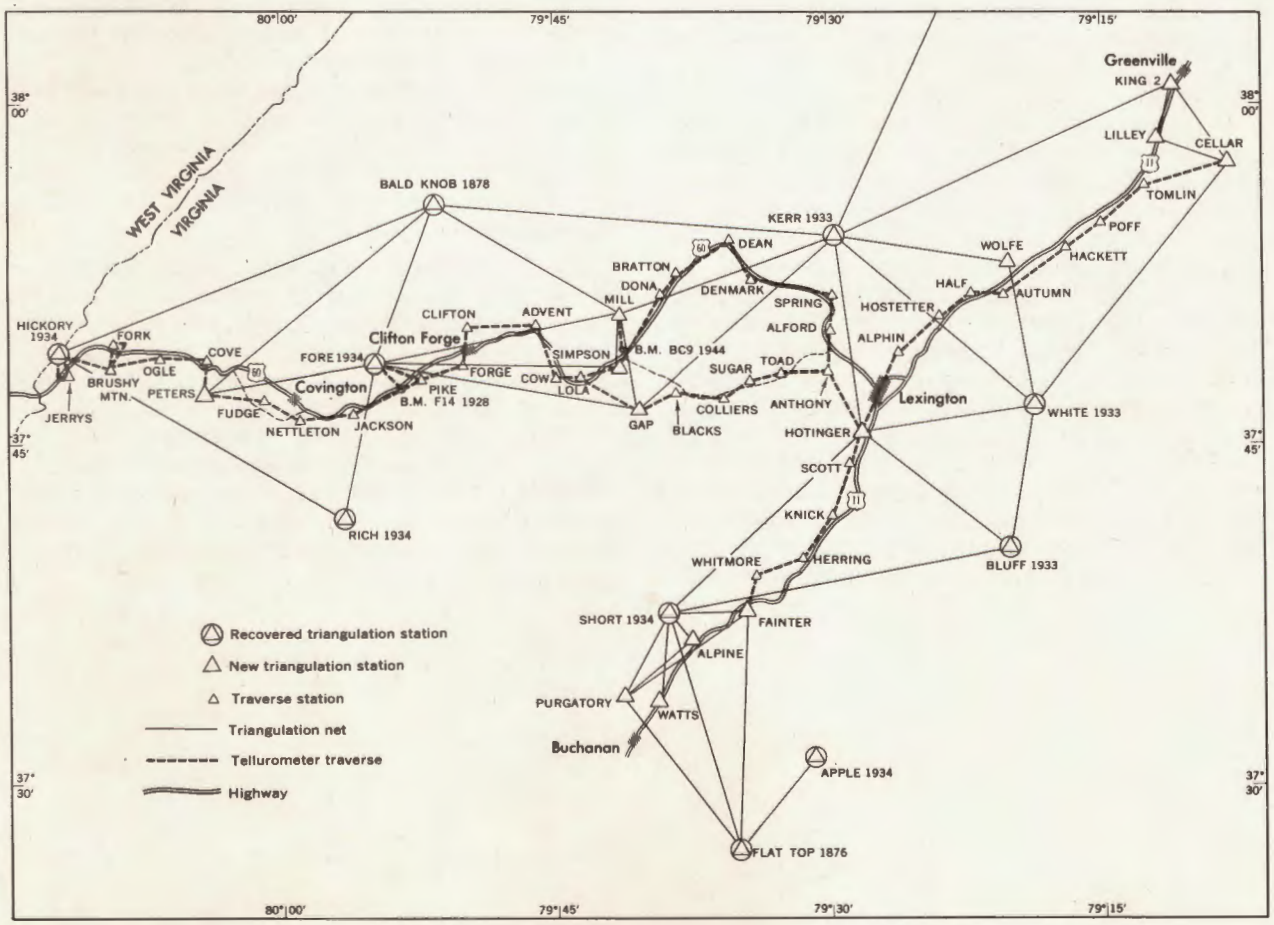

FIG. 2.—Geodetic control for Virginia state highways.